Building and Environment 45 (2010) 704–710

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Indoor thermal conditions and thermal comfort in air-conditioned domestic buildings in the dry-desert climate of Kuwait

Farraj F. Al-ajmi [a,*], D.L. Loveday [b]

[a] Department of Civil Engineering, College of Technological Studies, P.O. Box 42325, Shuwaikh 70654, Kuwait
[b] Department of Civil and Building Engineering, Loughborough University, Loughborough LE11 3TU, UK

ARTICLE INFO

Article history:
Received 31 March 2009
Received in revised form
30 July 2009
Accepted 16 August 2009

Keywords:
Kuwait domestic buildings
Kuwait domestic indoor environments
Domestic thermal comfort
Dry-desert climates

ABSTRACT

The summer season in the state of Kuwait is long with a mean daily maximum temperature of 45 °C. Domestic air conditioning is generally deployed from the beginning of April to the end of October. This accounts for around 75% of Kuwaiti electrical power consumption. In terms of energy conservation, increasing the thermostat temperature by 1 °C could save about 10% of space cooling energy [1,2]. However, knowledge of indoor domestic temperatures and thermal comfort sensations is important to aid future advice formulation and policy-making related to domestic energy consumption. A field study was therefore conducted during the summers of 2006 and 2007 to investigate the indoor climate and occupants' thermal comfort in 25 air-conditioned domestic buildings in Kuwait. The paper presents statistical data about the indoor environmental conditions in Kuwait domestic residences, together with an analysis of domestic-occupant thermal comfort sensations. With respect to the latter, a total of 111 participants provided 111 sets of physical measurements together with subjective information via questionnaires that were used to collect the data. By using linear regression analysis of responses on the ASHRAE-seven-point thermal sensation scale, the neutral operative temperatures based on Actual Mean Vote (AMV) and Predicted Mean Vote (PMV) were found to be 25.2 °C and 23.3 °C, respectively, in the summer season. Findings from this study provide information about the indoor domestic thermal environment in Kuwait, together with occupant thermal comfort sensations. This knowledge can contribute towards the development of future energy-related design codes for Kuwait.

1. Introduction

People in different climates feel comfortable at different indoor air temperatures. Such temperatures can differ considerably from the values adopted by national energy codes, which in turn can impact upon space energy consumption in buildings with air-conditioning systems, such as Kuwaiti domestic buildings. Kuwait, as in most countries with a dry-desert climate, has a long summer season with a mean daily maximum temperature of 45 °C [3]. Centralized air conditioning, which is generally deployed from the beginning of April to the end of October, accounts for around 75% of national electrical power consumption. Increasing the thermostat temperature setting in the summer season can potentially save significant electrical energy, which would, in turn, decrease energy expenditure, fossil fuel usage for generating electricity and consequently carbon dioxide emissions.

The indoor air temperature (or thermostat temperature) settings for all types of air-conditioned buildings and domestic buildings in particular, are often calculated based on the analytical model developed by Fanger [4]. This model, where comfort sensation is predicted via the Predicted Mean Vote (PMV), has been adopted by the ISO7730 [5] as the standard approach for thermal comfort evaluation.

Thermal comfort has been defined by ANSI/ASHRAE-55 [6] and ISO 7730 [5] as "That condition of mind which expresses satisfaction with the thermal environment". In the Fanger-based approach, human thermal comfort depends on the balance between the rate of production of metabolic heat and the rate of heat loss due to exchange with the surrounding environment. The Predicted Mean Vote (PMV) value is a function of a set of environmental conditions that include: air temperature, mean radiant temperature, relative humidity, air velocity, and the personal variables of clothing insulation, and rate of production of metabolic heat. An understanding

* Corresponding author. Tel.: +965 22314535.
E-mail address: farraj_alajmi@yahoo.co.uk (F.F. Al-ajmi).

0360-1323/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2009.08.018

of indoor thermal comfort is required to assist building designers in providing an environment that is acceptable to users and that does not impair the health and performance of the occupants of buildings.

A large number of thermal comfort studies have been conducted in buildings in all types of climates; most of these were carried out in tropical, subtropical and temperate climate zones [1–17], while other studies were performed in cold climate zones [18,19]. However, investigation of indoor thermal comfort in buildings for countries located in dry-desert climates is limited, although some studies can be mentioned (Baker and Standeven [20]; Cena and de Dear [2]). Their results indicated that the Actual Mean Vote (AMV) of the occupants in air-conditioned buildings is greater than that of the PMV. Saeed [21,22] conducted research in the dry-desert region in Riyadh, Saudi Arabia and measured thermal comfort for classroom students in King Saud University and at Friday prayers during the hot season. The results indicate a fairly good agreement with Fanger's model in both studies, whilst subjects attending Friday prayer would prefer a cooler climate than the one recorded in his survey. In later studies, clothing insulation (clo values) in both studies was estimated with disregard to the assessment methods of ISO 9920 [23] (i.e. estimation of clothing properties). In the study reported here, however, field experiments were conducted in twenty-five air-conditioned domestic buildings using survey questionnaires and physical measurements to collect data during the summers of 2006 and 2007.This study also takes into account the clothing insulation values that were calculated by Al-ajmi et al. [24,25].

The main objective of this paper is to investigate the indoor climate and thermal conditions in air-conditioned domestic buildings situated in the dry-desert climate of Kuwait. This will provide information that can assist future policy aimed at enhancing energy conservation and reducing carbon emissions.

2. Context

2.1. The outdoor condition

Kuwait is typical of a dry-desert climate with the highest air temperature being recorded in July and August with an afternoon average maximum of 45 °C. Summer starts at the beginning of April and continues until the end of October, with a mean air temperature of 37 °C [26]. In addition, the air is generally dry with an average relative humidity ranging from 14–42% in the summer to 42–80% in the winter. In winter, the weather is comfortably cool, generally mild, with a monthly mean temperature of 10 °C, and a minimum temperature recorded as being occasionally below 5 °C. Precipitation is low and dust storms are common [26]. Kuwait is located between latitude 29° 13′ North and longitude 47° 58′ East at an elevation above mean sea level (m.s.l.) of 45 m. Fig. 1 gives the hourly values of dry and wet bulb temperatures for the summer harshest period, from the beginning of July to the middle of August in the State of Kuwait.

2.2. Buildings surveyed

Twenty-five domestic buildings were selected to be surveyed in Kuwait. Buildings were selected evenly over the five provinces of Kuwait (i.e. Capital, Hawalli, Aljahra, Alahamidi and Mobarak Alkabeir). The sizes of the selected buildings ranged from one to three floors with a plot area of 400 m^2. Whilst it was impossible to cover all domestic building types in Kuwait in this study, those buildings selected were considered from the perspective of the following specific criteria:

- Centralized air conditioning with similar cooling size.
- Typical type, size and construction materials.
- Selected buildings are not older than 10 years and distributed evenly amongst the five provinces of Kuwait.

In this way, a reasonable sample of housing types from the Kuwaiti domestic building stock is covered by this investigation.

3. Field survey

The thermal environment and comfort survey was carried out in 25 domestic buildings across the five provinces of Kuwait. A total of 111 subjects providing 111 sets of physical measurements, and questionnaires were used to collect subjective data. The subjects consisted of 56 (52%) males and 52 (48%) females. The age of the inhabitants ranged from 12 to 65 years, with a mean age of 32.1 years. Their mean height was 159.6 cm and their mean weight was 68.7 kg, (see Table 2). The fieldwork was carried out in the State of Kuwait during the summer season using the following survey procedures. Note that, due to cultural requirements, it was necessary that the survey was conducted by a female experimenter.

3.1. Subjective measurements

The subjective study involved collecting data using questionnaires which were given to each subject to complete simultaneously with collection of the physical measurements in each domestic building. The subjective questionnaires and a description of the experimental work procedure had been translated carefully into the Arabic language in order that the occupants could follow and understand. The questionnaire addressed the following areas: (i) background and personal information; (ii) current clothing garments; (iii) subjective thermal sensation vote (the Actual Mean Vote, or AMV) based on the ASHRAE-seven-point scale and consisting of: (−3) cold, (−2) cool, (−1) slightly cool, (0) neutral, (+1) slightly warm, (+2) warm, and (+3) hot; (iv) humidity sensation, scaled as: (−3) very humid, (−2) humid, (−1) slightly humid, (0) neither humid nor dry, (+1) slightly dry, (+2) dry, and (+3) very dry. (v) Air movements' sensation scaled as: (−3) very low, (−2) low, (−1) slightly low, (0) neither high nor low, (+1) slightly high, (+2) high, and (+3) very high.

The subjects were required to make only one choice from the scale for each question.

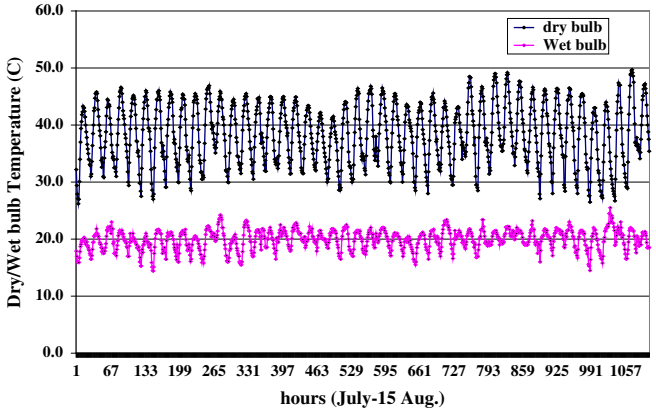

Fig. 1. Hourly dry and wet bulb temperature for period between beginning of July to mid August in the state of Kuwait [26].